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# Tevatron Upgrades

Vladimir Shiltsev  
Fermilab BD/Tevatron

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# Content:

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- Motivation, performance goals
- Subprojects:
  - WBS
  - Technical issues
  - Cost/labor estimates
  - Recent progress/Status/Plans
  - Missing Resources
- Milestones

# Tevatron in Run II: Goals/Issues

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- differences between now ( $L \sim 37\text{e}30$ ) and then ( $L = 290\text{e}30$ ):

	$L$ gain
➤ more protons	x 1.2
➤ more pbars	x 5.9 (to $\frac{1}{2}$ of p's)
➤ shorter bunches	x 1.1
➤ ~ same transverse emittances	
	total: x 7.8

- as the result:
  - Stronger beam-beam force on pbars
  - Noticeable beam-beam force on protons
  - Possible coherent beam-beam phenomena
  - Tighter control of tunes, orbit, coupling, chromaticities
  - Tighter tolerances on transfers: intensity and emittances
  - Stability concerns for both beams
  - Need of luminosity leveling above  $200(?)\text{e}30 \text{ s}^{-1} \text{ cm}^{-2}$

# Tevatron Upgrade Projects

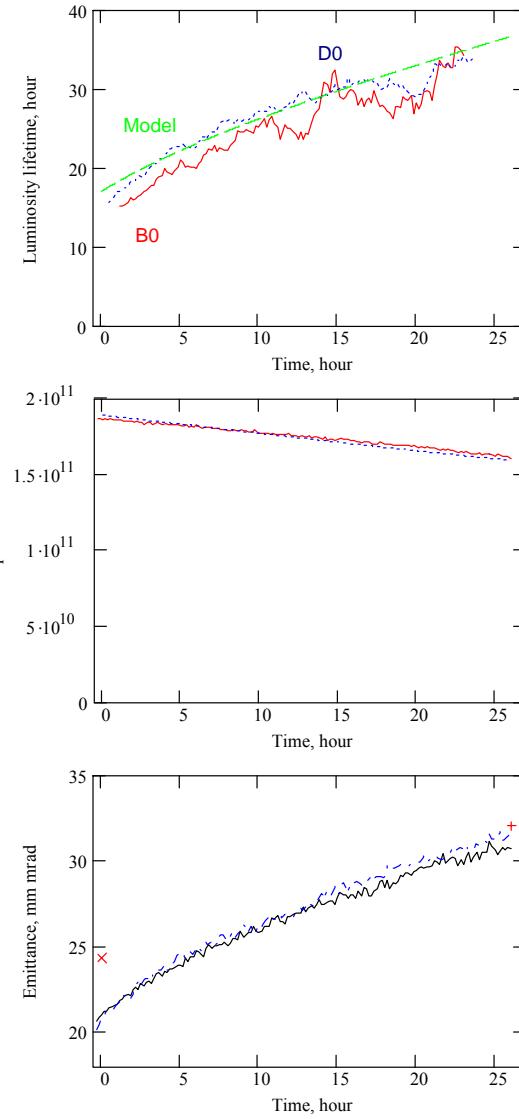
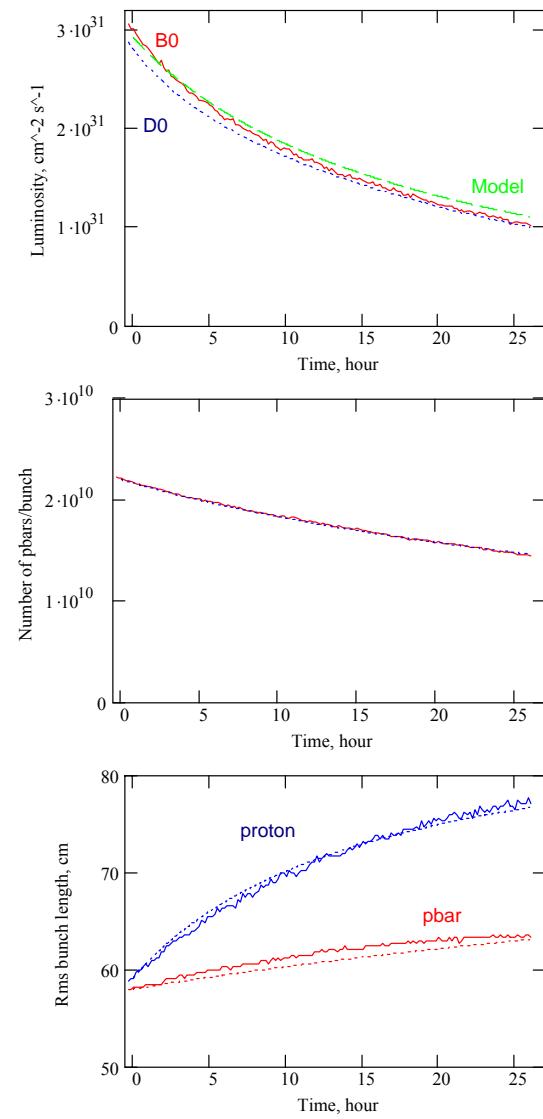
WBS	Task	In Charge	Labor Est (\$K)	Labor Cont	M&S Est (\$K)	M&S Cont	Start
1.3.4	<b>Tevatron High Luminosity</b>	V Shiltsev	<b>7,588</b>	<b>51%</b>	<b>5,103</b>	<b>47%</b>	<b>1/1/03</b>
1.3.4.1	Tevatron Task Force	V. Lebedev	1,856	40%	0	0%	1/1/03
1.3.4.2	Beam-beam Limitations	T. Sen	453	60%	5	40%	1/1/03
1.3.4.3	Active Beam-Beam Compensation	V Shiltsev	1,400	64%	1,380	57%	1/1/03
1.3.4.3.1	BBC: Tevatron Electron Lens	V. Shiltsev	1,088	55%	1,250	53%	1/1/03
1.3.4.3.2	BBC: Wires	T. Sen	312	94%	130	100%	4/1/03
1.3.4.4	<b>Increased Helix Separation</b>	R. Moore	<b>1,222</b>	<b>40%</b>	<b>1,847</b>	<b>27%</b>	<b>4/1/03</b>
1.3.4.4.1	Optimize separation with present Separators	Y. Alexahin	39	60%	0	0%	5/1/03
1.3.4.4.2	Tevatron Polarity Switches for Separators	B. Hanna	98	47%	237	41%	11/3/03
1.3.4.4.3	Long Separators	R. Moore	735	25%	1,570	23%	9/2/03
1.3.4.4.4	Coated Separators	B. Hanna	222	70%	40	100%	5/1/03
1.3.4.4.5	Additional Separators	B. Hanna	128	60%	0	0%	4/1/03
1.3.4.5	<b>Luminosity Leveling</b>	M. Martens	<b>13</b>	<b>54%</b>	<b>0</b>	<b>0%</b>	<b>12/1/04</b>
1.3.4.6	<b>Improved Control and Diagnostics</b>	J. Steimel	<b>1,742</b>	<b>55%</b>	<b>1,500</b>	<b>61%</b>	<b>1/1/03</b>
1.3.4.6.1	abort gap monitor	H. Cheung	31	60%	30	60%	4/1/04
1.3.4.6.2	Tev Dampers	J. Steimel	52	60%	0	0%	12/1/03
1.3.4.6.3	p/pbar Tune Tracker	CY Tan	11	60%	30	60%	11/3/03
1.3.4.6.4	Tevatron BPM Upgrade	J. Steimel	412	57%	900	60%	8/1/03
1.3.4.6.5	Tevatron IPM	A. Jansson	324	57%	300	60%	5/1/03
1.3.4.6.6	B-field diagnostics	P. Bauer	846	52%	160	53%	1/1/03
1.3.4.6.7	1.7 GHz Schottky Detector	A. Jansson	65	60%	30	60%	3/3/03
1.3.4.6.8	Head-tail Monitor	V. Ranjbar	0	0%	50	100%	11/1/04
1.3.4.7	<b>Tevatron Vacuum Improvements</b>	B. Hanna	<b>12</b>	<b>40%</b>	<b>90</b>	<b>40%</b>	<b>10/17/03</b>
1.3.4.8	<b>Tevatron Alignment</b>	R. Stefanski	<b>891</b>	<b>60%</b>	<b>281</b>	<b>60%</b>	<b>1/1/03</b>
1.3.4.8.2	Orbit/aperture optimization	J. Annala	314	60%	0	0%	1/1/03
1.3.4.8.3	Tevatron On-line Level System	J. Volk	291	60%	181	60%	3/3/03
1.3.4.8.4	Magnet Alignment	R. Stefanski	118	60%	100	60%	8/25/03
1.3.4.8.5	SC Coil Realignment/Smart Bolts	D. Harding	168	60%	0	0%	8/25/03

# Tevatron Task Force

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- Addresses following topics :
  - Present Tevatron Configuration (lattice functions, orbit correction, coupling, helices, etc)
  - Beam diffusion, luminosity lifetime modeling
  - Helix optimization
  - Beam stability
  - Other beam physics phenomena
- Provides input to other Tev Upgrade projects
  - Alignment, BBCCompensation, Diagnostics, Larger Helices
- Takes part in the beam studies (including planning)
- Very efficient inter-department group of the most experienced scientists
  - BeamPhysDept+TevDept+PbarDept+SDAGroup

# Tevatron Task Force



← Comparison of measured and predicted evolution of beam parameters in store #1937

← From "Report on Tevatron Modeling and Accelerator Physics", available on DoE review Web site

← Talks at joint Tev/Phys breakout session, today 4pm-5pm, 1 East

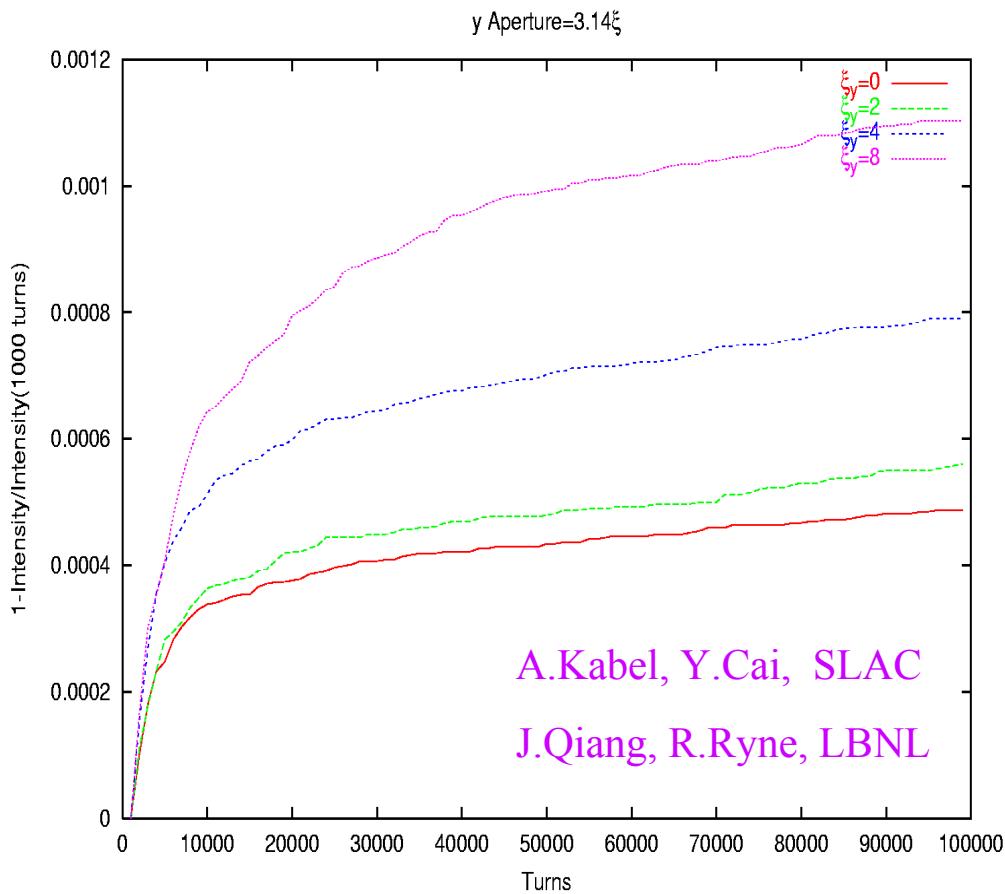
# Beam-Beam Limitations

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- Project to investigate beam-beam limitations in the Tevatron collider
  - explain experimental data/observations
  - provide recommendations for operation
  - quantitative predictions for the Run II Design parameters
- Various methods:
  - analytic calculations
  - numerical tracking (collaboration with SLAC and LBNL)
  - beam studies (planning, execution, analysis)
- Provides input to other Tev Upgrade projects
  - BBCompensation, Diagnostics, Larger Helices

# Beam-Beam Limitations

Pbar loss at injection, first 2 sec ,  
for different machine chromaticities



- Progress in analysis
  - 150 GeV pbar lifetime simulations
  - DA at 150 GeV, tunes, "clothed" orbit
- Progress in experiment hampered by lack of the study time
  - Parametrization
  - Beam-beam on protons
  - Other than 36x36, etc
- Joint Tev/Phys breakout session, tomorrow, Tue, 8am-10am, 1 East

# Attacking Beam-Beam Limitations

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- Beam-Beam Compensation    WBS 1.3.4.3
  - With Electron Lenses
  - With Wires
  
- Larger Helix Separation    WBS 1.3.4.4
  - Open aperture
  - More separators
  - Stronger separators

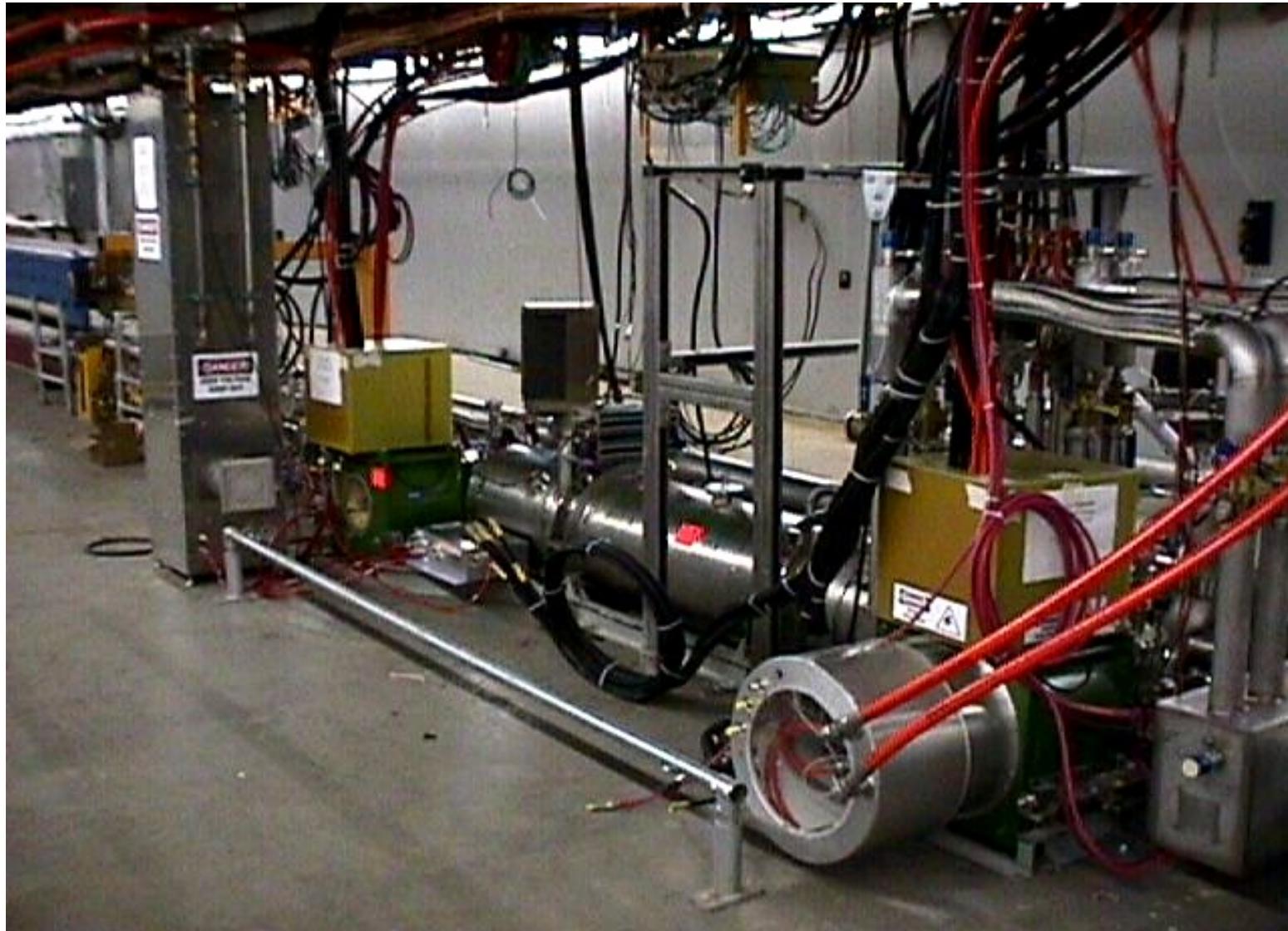
# BBC: Tevatron Electron Lens

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- R&D project to compensate of long-range/head-on beam-beam effects with use of high-current low-energy electron beams
  - Status/plans: (show pic)
    - Progress in understanding lifetime reduction
    - Promising results with TEL-1 (show plot)
    - People needed → pursuing ( see last slide )
    - Plan for diagnostics upgrade
    - Study time needed to understand modifications
    - Proceed with TEL-2
  - Discussion at joint Tev/Phys breakout session tomorrow, 8-10am, 1 East
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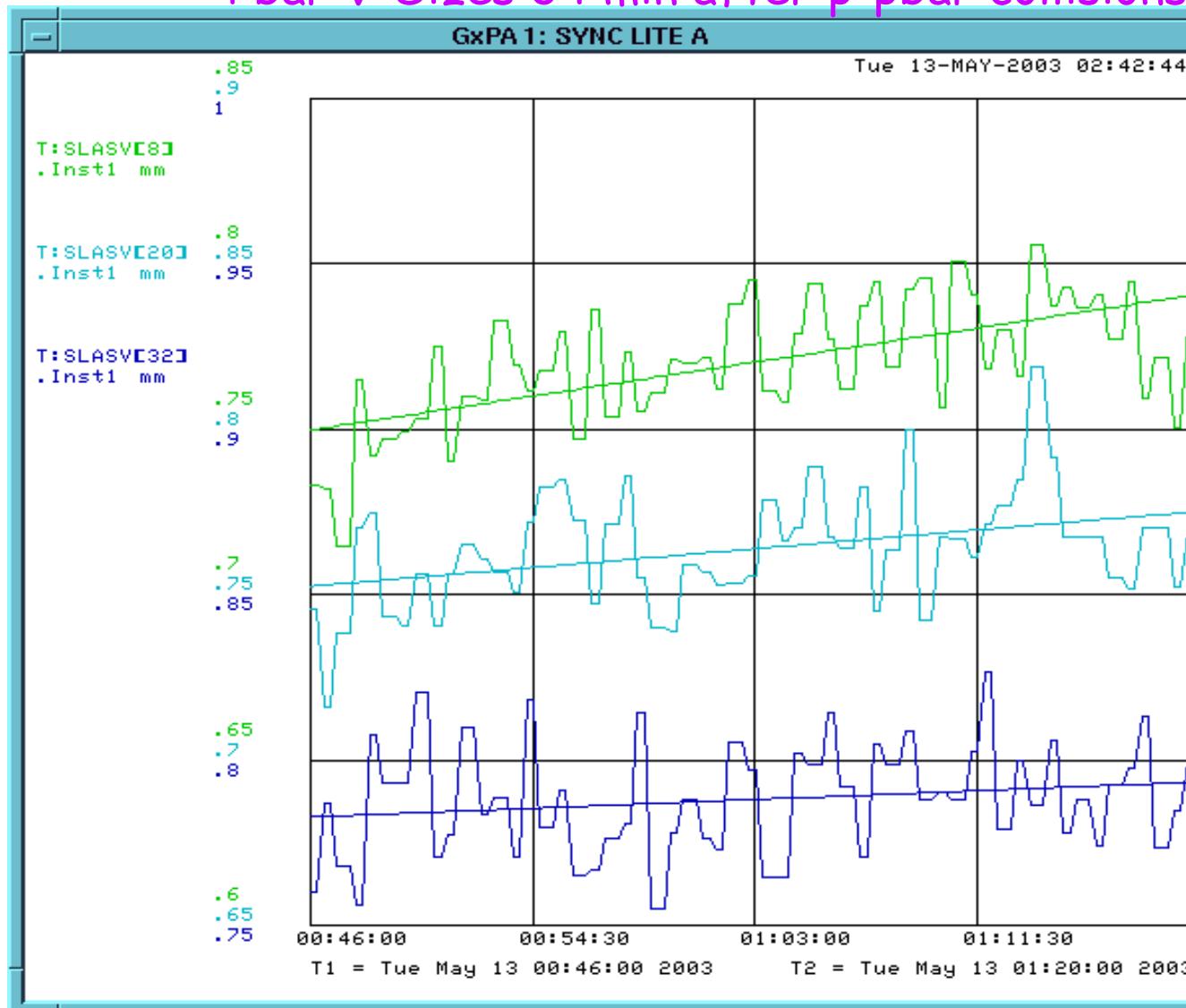
# Tevatron Electron Lens #1

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# First Indication of Beam-Beam Compensation

Pbar V-Sizes 34 min after p-pbar collisions initiated



Store #2540

May 12, '03

A9 : 4.1  $\pi$  mm mrad/hr

A21 : 2.2  $\pi$  mm  
mrad/hr

A33 : 1  $\pi$  mm mrad/hr

-TEL on it

# Compensation with Wires

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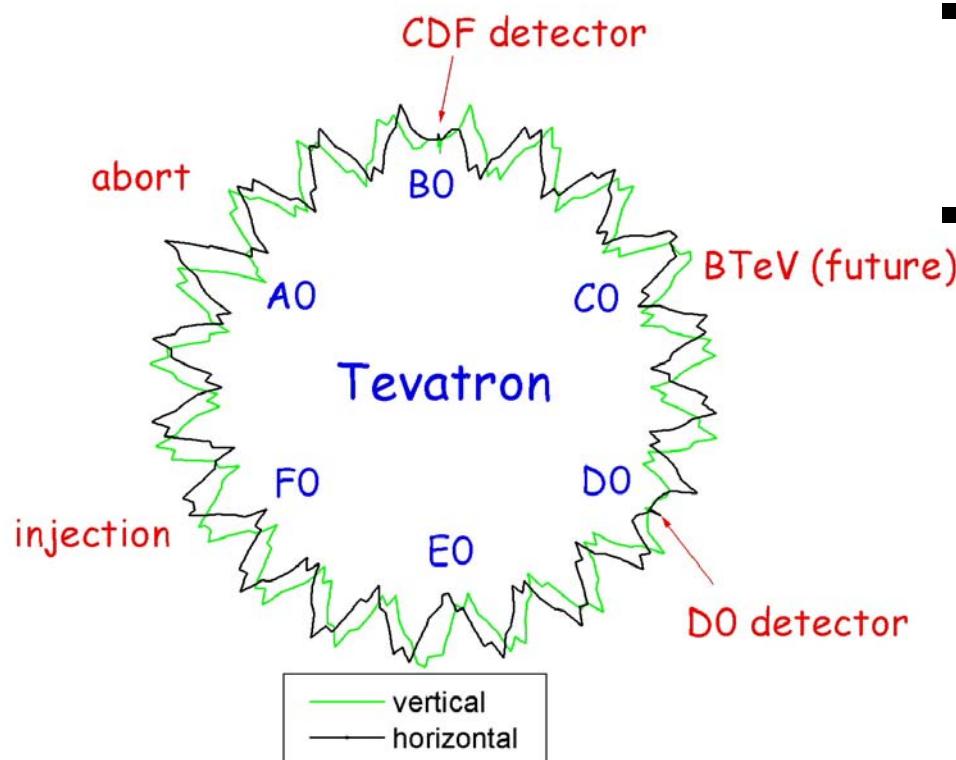
- R&D on active compensation of long-range beam-beam effects with use of number of conductive wires carrying high current in vicinity of pbar beam ( $\sim 200\text{A}\cdot\text{m}$ )
- Status/plans:
  - Physics analysis underway
  - Decision on prototype - Oct 2003
  - design, build, install prototype station (08/04)
- Discussion at joint Tev/Phys breakout session tomorrow, 8-10am, 1 East

# Increased Helix Separations

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- Goal of the project is to reduce strength of beam-beam resonances by increasing beam separation
    - Will not reduce head-on beam-beam interaction
    - Will not help much at 150 GeV (aperture limited)
  - Status/plans:
    - New helix at 150, ramp, squeeze: FY'03 → FY'04
    - Aperture studies ~complete
    - Need study time to implement
    - More separators
    - Stronger "coated" electrode R&D started (TD)
  - Optimal helix solutions come from the Tev Task Force
  - TD to make essential contribution to design and fabrication
-

# Helix Improvements

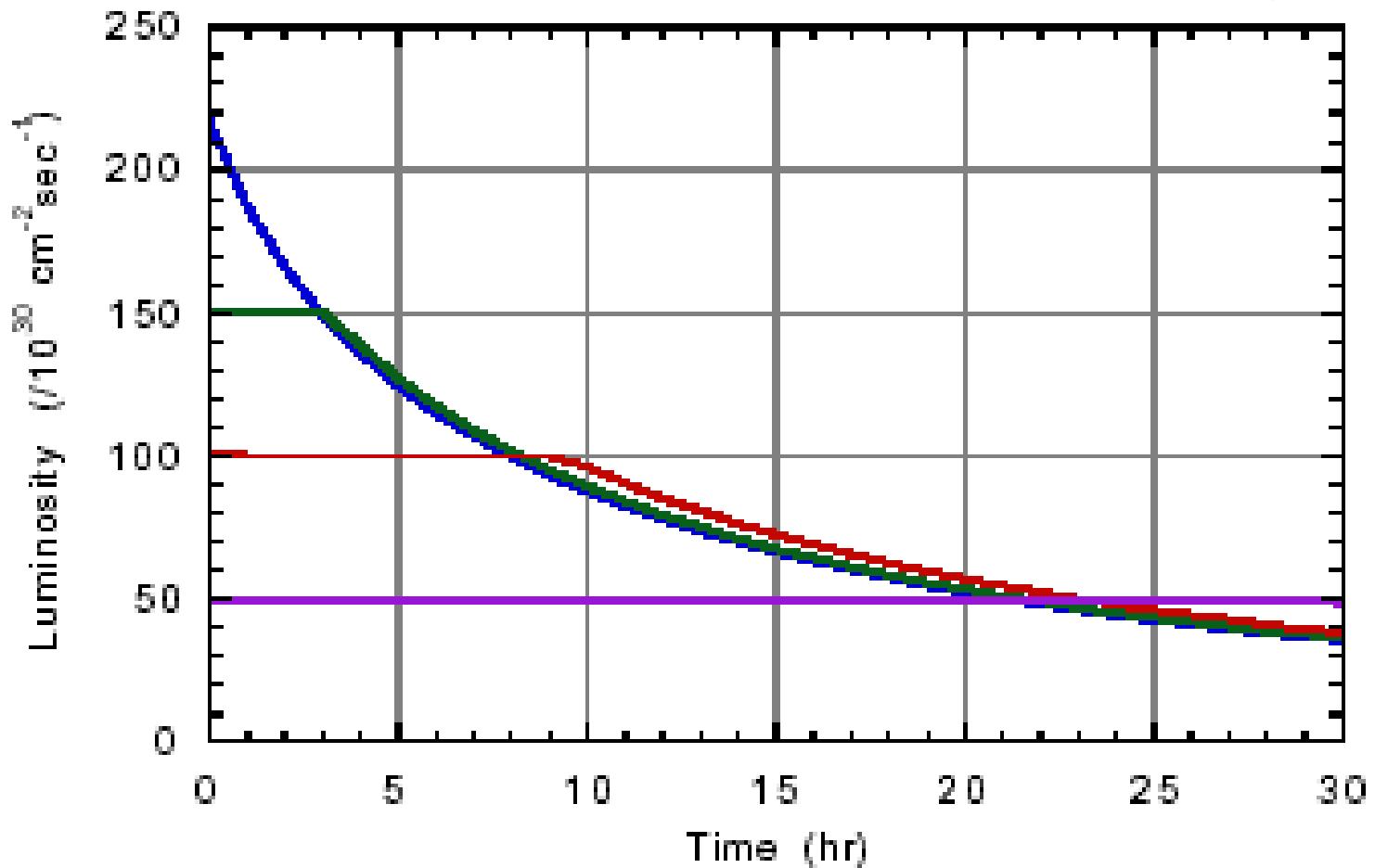


- Quantitative improvement:
  - Increase minimum separation in ♦'s
- Qualitative improvements:
  - Decrease strength of resonances
  - Decrease maximum separation in mm

Modification	near-misses gain %	Ringwide gain%
10% separator voltage increase	10	10
50 rad half-crossing angle	21.5	~0
Additional arc modules	7.7	15
Increase IR separator strength	19	19
<b>TOTAL GAIN</b>	<b>71</b>	<b>50</b>

# Luminosity Leveling

M.Martens, V.Lebedev



- vary beta\* to keep # int/crossings at acceptable level (TBD by experiments), ~12% hit on integrated luminosity

# Improved Control & Diagnostics

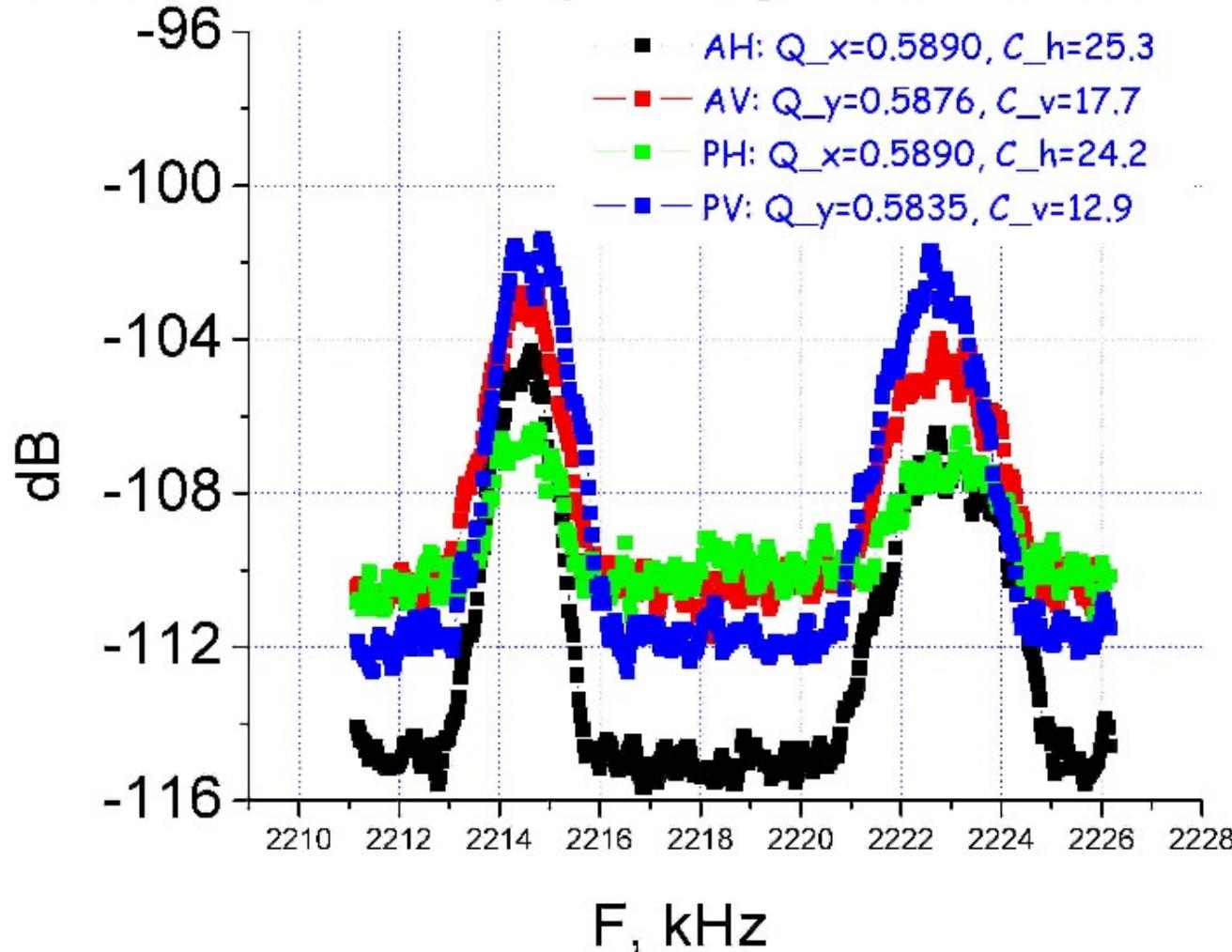
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- WBS 1.3.4.6 includes:

- Abort gap monitor
- Tev dampers
- p/pbar tune tracker
- Tev BPM upgrade
  - Technical design review in Oct 03
  - Build and install in Fy'04
- Ionization Profile Monitors
  - Design review in Sep 03
- On-line B-field measurements @ MTF (TD)
- 1.7GHZ Schottky detector (see slide)
- Head-tail monitor

# 1.7 GHz Schottky Detector

2780: new Schottky spectra, gated on all bunches



# Vacuum Improvement

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- Goal to maintain and improve Tevatron vacuum
  - Progress:
    - poor vacuum in P1 and A1 line → Tev FO - shutdown'03
    - Fix known leaks
    - "Licensing" every new piece
  - Better coordination of the activity
  - Plan to improve vacuum diagnostics (RGAs)
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# Tevatron Alignment

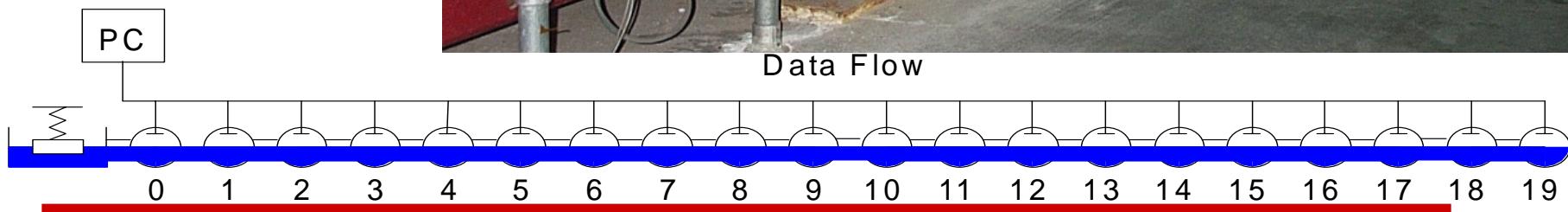
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- To keep Tev magnets aligned and correctors not saturated, establish configuration control
  - Status/plans:
    - 10 tiltmeters report on-line
    - Review of alignment work for Aug'03 shutdown (07/03)
    - Upgrade survey network, measurements in the tunnel
    - Adjust cold mass suspensions in ~100 dipoles (reshimming)
    - Real-time motion sensors on Tevatron components
    - Adjustment of magnet positions and rolls where necessary
    - Replace rusty stands
  - In close cooperation with the Tev Task Force
  - Significant contributions from TD and PPD
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# Tev On-Line Survey System: Elevations and Rolls

- need "200(800) water level/roll sensors, accuracy 2  $\Omega$ m, 0.1 mrad
- 20 sensors 600 m system works fine in MI-8 tunnel for year (0.05  $\Omega$ m resol'n) → to be moved to Tevatron B-sector in Aug'03
- TD involved

J.Volk, BINP(Novosibirsk), D.Plant, R.Stefanski, V.Shiltsev



# Milestones for WBS 1.3.4

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1.3.4	Tevatron High Luminosity	V Shiltsev	Date	
1.3.6.2.1	<b>Review: Tevatron Upgrade Plan (Milestone)</b>	J. Spalding	9/29/03	B
1.3.4.3.1.5	Review TEL R&D (Milestone)	V. Shiltsev	3/23/04	C
1.3.4.3.1.6	Decision on second TEL (Milestone)	V. Shiltsev	12/15/04	B
1.3.4.3.1.11	<b>TEL System Operational (Milestone)</b>	J. Spalding	5/23/07	A
1.3.4.3.2.3	Decision to proceed with wire station prototype (Milestone)	V. Shiltsev	9/29/03	B
1.3.4.3.2.8	Decision on wire BBC (Milestone)	V. Shiltsev	1/19/05	B
1.3.4.3.2.13	<b>Wire BBC Operational (Milestones)</b>	J. Spalding	4/23/07	A
1.3.4.4.4.2	Decision on high voltage separators (Milestone)	V. Shiltsev	4/28/04	B
1.3.4.4.5.3	Decision on separators/magnets (Milestone)	V. Shiltsev	9/1/03	B
1.3.4.4.3.11	<b>Increased BB separation operational (milestone)</b>	Jeff Spalding	3/22/07	A
1.3.4.6.4.2	Tev BPM: Review (Milestone)	J. Steimel	10/1/03	C
1.3.4.6.5.3	Tev IPM Design Review, decision to proceed (Milestone)	A. Jansson	10/1/03	C
1.3.4.8.1	Review Tevatron Alignment Plans	R Stefanski	8/1/03	C

# Resources

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- Tev RLS contains 14 FTE not yet identified
  - 6 Scientists
  - 5 Engineers
  - 3 Computer Professionals
- 11 out 14 will come from
  - BD resources redirected
  - help from other Divisions
- 3 openings:
  - 2 Accel. Physicists ( Tev Task Force, BBCompens)
  - 1 Engineer (Beam-Beam Compensation)
  - BD Head is already working on that (an offer is out)

# Back-up slides

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- Now vs Run Ib
- FY04 vs Now
- Run II Design vs Now
- Misc

# Run II (without the Recycler) and Run Ib

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- Projected -  $5.3 \times (8.5 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1} / 1.6 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1})$
- Delivered\* -  $1.94 \times (3.1 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1} / 1.6 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1})$
- More Pbars
  - projected - 3.3x
    - More protons on target - 2x ( $5 \times 10^{12} / 2.5 \times 10^{12}$ )
    - Faster Pbar cycle rate - 1.6x (2.4sec/1.5sec)
  - delivered\* - 1.9x
    - More protons on target - 1.9x ( $4.7 \times 10^{12} / 2.5 \times 10^{12}$ )
    - Faster Pbar cycle rate - 1x (2.4sec/2.4sec)
- More Protons
  - projected - 1.17x ( $270 \times 10^9 / 230 \times 10^9$ )
  - delivered\* - 0.83x ( $192 \times 10^9 / 230 \times 10^9$ )
- Shorter Bunch lengths
  - projected - 1.25x (0.37m <- 0.6 m)
  - delivered\* - 1x (0.6m <- 0.6 m)
- Higher Energy
  - projected - 1.11x (1000 GeV/ 900 GeV )
  - delivered\* - 1.09x (980 GeV/ 900 GeV )

\*Based on 75 Stores between 2/10/03 – 6/5/03

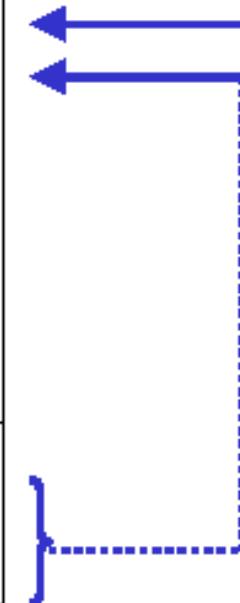
# FY03 - FY04 Collider Parameters

Parameter	Average *	St. Dev. *	Best Integrated	Best Peak	Phase 1	
Initial Luminosity (CDF)	31.2	9.6	42.0	47.4	68.0	x10 <sup>30</sup> cm <sup>-2</sup> sec <sup>-1</sup>
Average Instantaneous Luminosity (CDF)	19.4	6.8	22.3	27.0	37.9	x10 <sup>30</sup> cm <sup>-2</sup> sec <sup>-1</sup>
Integrated Luminosity per Store (CDF)	985.7	450.5	1713.0	1650.0	2251.3	nb <sup>-1</sup>
Luminosity per week (CDF)	4.7	2.6	4.6	7.0	10.9	pb <sup>-1</sup>
Number of Stores per Week	4.7	-	-	-	4.8	
Store Length	14.4	5.5	21.3	17.0	14.5	Hours
Intentional Store Length	16.6	3.4	21.3	17.0	14.5	Hours
Aborted Store Length	10.6	6.4	-	-	-	Hours
Store Hours per week	68.6	31.9	46.3	91.6	70.3	Hours
Time spent stacking per store	14.6	3.4	19.5	20.9	14.5	Hours
Shot Setup Time	2.8	2.6	1.8	2.0	2.0	Hours
Store Lifetime	13.6	3.8	14.9	13.6	10.8	Hours
Protons per bunch	192.1	29.0	203.8	242.0	240.0	x10 <sup>9</sup>
Start Stack	135.3	25.1	166.0	173.0	174.3	x10 <sup>10</sup>
End Stack	11.2	13.6	12.0	11.0	0.0	x10 <sup>10</sup>
Zero Stack Stack Rate	11.7	1.6	11.7	11.7	18.0	x10 <sup>10</sup> /Hour
Zero Stacking Rate Stack Size	303.7	1.7	303.7	303.7	300.0	x10 <sup>10</sup>
Pbar Transfer efficiency to Low Beta	57.9	7.5	57.7	56.7	75.0	%
HourGlass Factor	0.64	0.03	-	0.65	0.65	

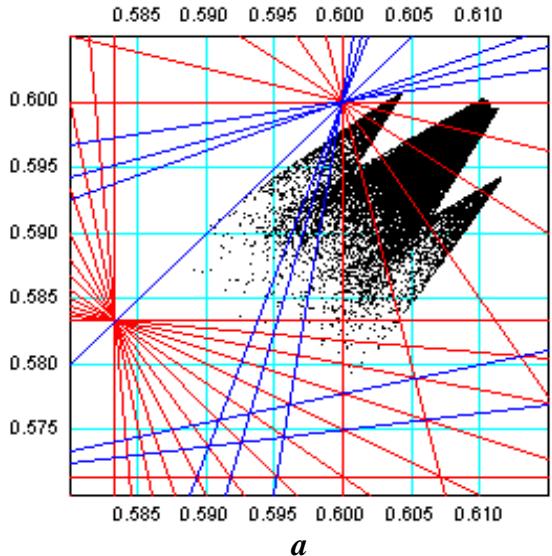
\*Based on 75 Stores between 2/10/03 – 6/5/03

# Run II: Design/Now

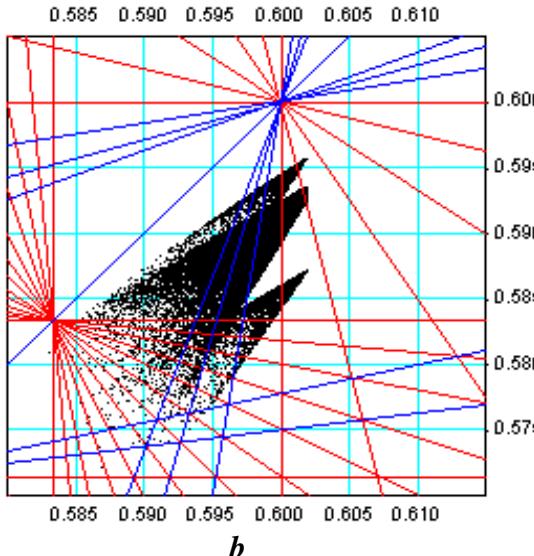
Parameter		May 03 Average	Run II Design	Ratio
Peak Luminosity	$\times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$	3.7	29	7.8
Store hours per week		75	97	1.3
Store Duration	hr	15	15	1.0
Integrated Luminosity	$\text{pb}^{-1}/\text{wk}$	5.9	55	9.3
Number of Bunches		36	36	1.0
Protons/bunch	$\times 10^{10}$	22	27	1.2
Antiprotons/bunch	$\times 10^{10}$	2.2	13	5.9
$\beta^*$	cm	35	35	1.0
MI extraction Longitudinal Emittance	eV s	3.5	2.5	0.7
Bunch Length (rms)	m	0.6	0.5	0.9
Proton Transverse Emittance (at collision)	$\pi\text{-mm-mrad}$	20	18	0.9
Antiproton Transverse Emittance (at collision)	$\pi\text{-mm-mrad}$	18	18	1.0
Hourglass Form Factor		0.6	0.63	1.1
Pbar Transmission Efficiency	%	60	80	1.3
Stack Used	$\times 10^{10}$	134	583	4.4
Avg. Antiproton Production Rate	$\times 10^{10}/\text{hr}$	8.3	40	4.8



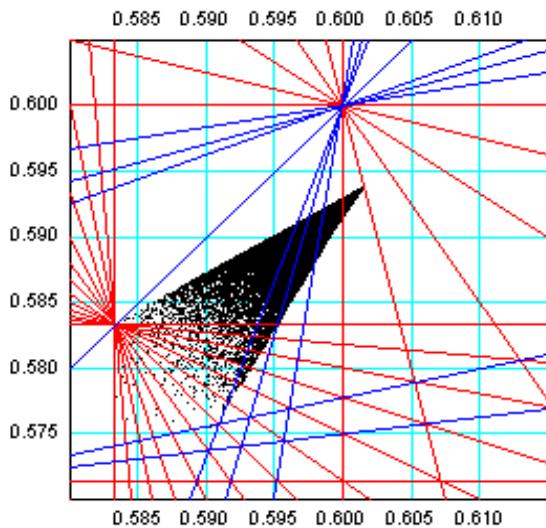
# Beam-Beam Compensation



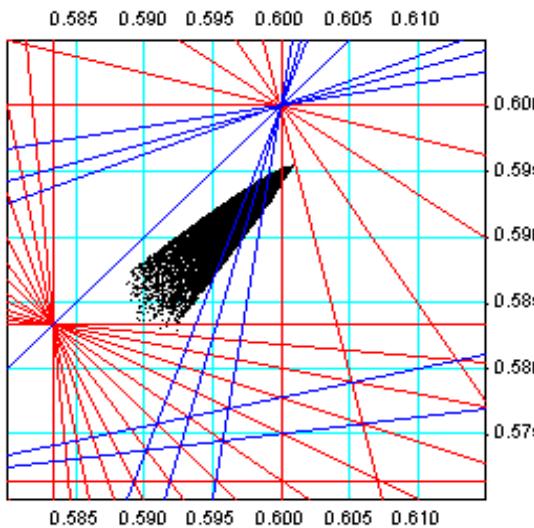
*a*



*b*



*c*

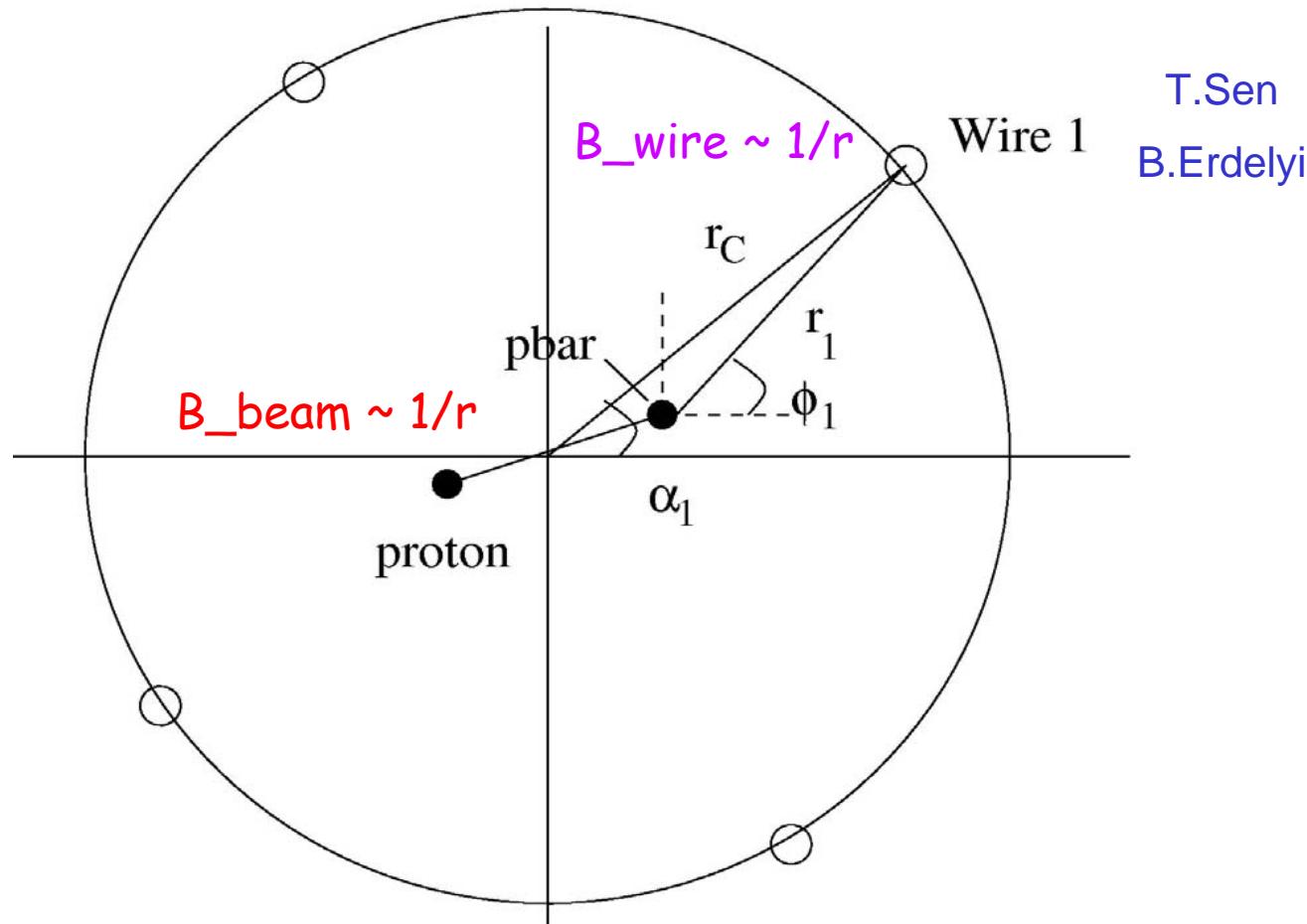


*d*

Yu.Alexahin

- compensate beam-beam tune shifts
  - a) Run II Goal
  - b) one TEL
  - c) two TELs
  - d) 2 nonlinear TELs
- requires
  - electron current ✓
  - stability ✓
  - centering ✓
  - shaping ✓
- other considerations
  - use at 150 GeV, ramp, squeeze - ?
  - abort gap cleaning

# Wire Compensation



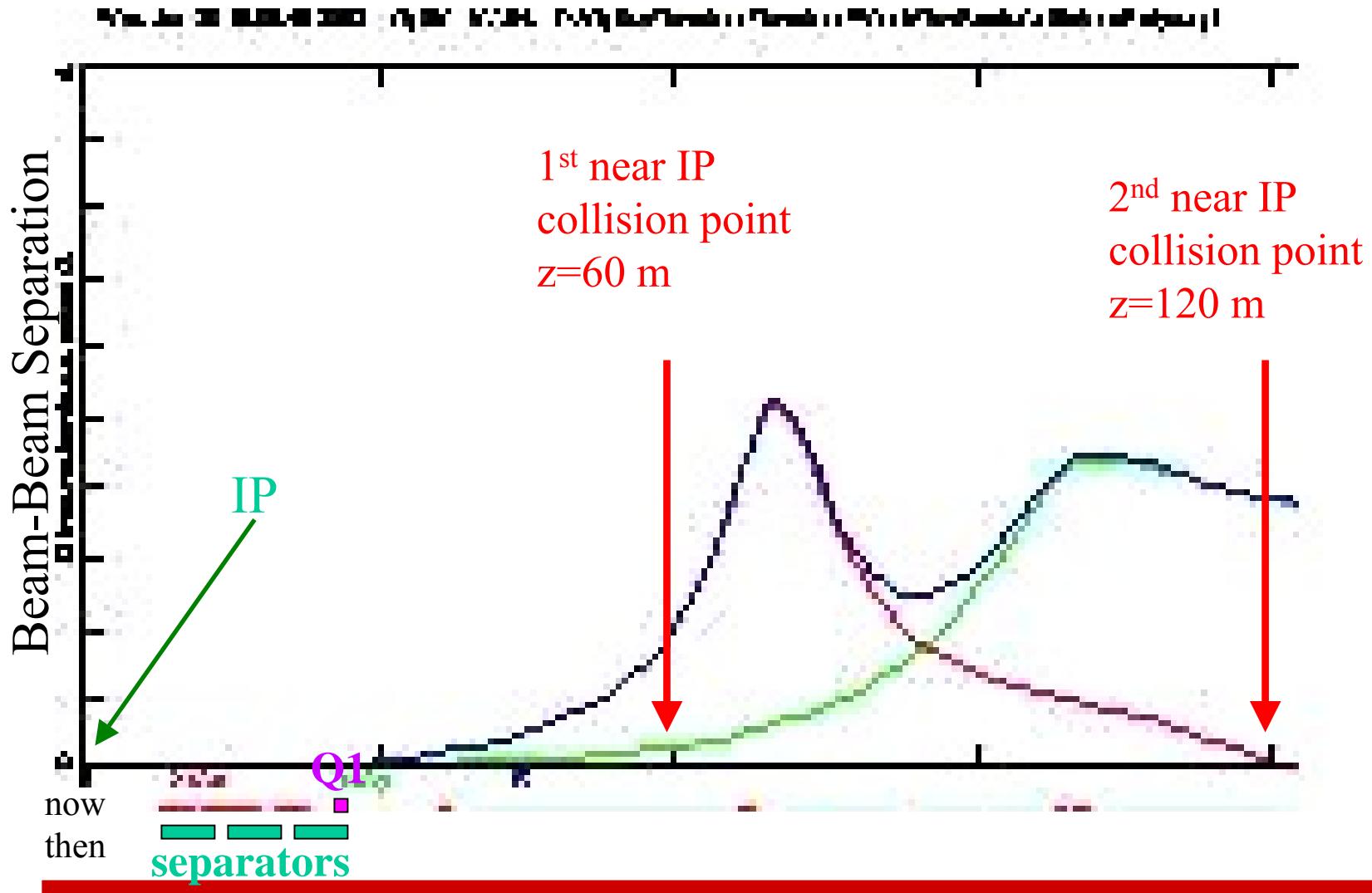
- Wire mimics long-range B-field of proton beam, compensates
- ~ 200A in ~ 4 wires at ~ 4 locations around the Tevatron

# Increased Helix Separation

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<b>1.3.4.4</b>	<b>Increased Helix Separation</b>			<b>\$0.00</b>		<b>4/1/2003 8:00</b>	<b>1044 days</b>
<b>1.3.4.4.1</b>	<b>Optimize separation with present Sepa</b>			<b>\$0.00</b>		<b>5/1/2003 8:00</b>	<b>166 days</b>
1.3.4.4.1.1	Design new Helix and investigate Separato			\$0.00	C	5/1/2003 8:00	66 days
1.3.4.4.1.2	Implement new separator Protocol			\$0.00	C	11/19/2003 8:00	22 days
<b>1.3.4.4.2</b>	<b>Tevatron Polarity Switches for Separat</b>			<b>\$0.00</b>		<b>11/3/2003 8:00</b>	<b>209 days</b>
1.3.4.4.2.1	Purchase parts			\$165,000.00	B	11/3/2003 8:00	1 day
1.3.4.4.2.2	Assemble and test switches			\$64,000.00	B	1/5/2004 8:00	88 days
1.3.4.4.2.3	Install switches in service buildings			\$8,000.00	C	5/6/2004 8:00	66 days
1.3.4.4.2.4	Commission with beam			\$0.00	C	8/5/2004 17:00	10 days
<b>1.3.4.4.3</b>	<b>Seperator Upgrade</b>			<b>\$0.00</b>		<b>5/1/2003 8:00</b>	<b>956 days</b>
1.3.4.4.3.1	R&D on high voltage separator design			\$40,000.00	C	5/1/2003 8:00	260 days
1.3.4.4.3.2	Decision on high voltage separators (Milest			\$0.00		4/28/2004 17:00	0 days
1.3.4.4.3.3	retrofit spare separators			\$0.00	C	4/29/2004 8:00	130 days
1.3.4.4.3.4	replace separators -1			\$0.00	C	5/29/2006 8:00	33 days
1.3.4.4.3.5	retrofit separators			\$0.00	C	7/13/2006 8:00	88 days
1.3.4.4.3.6	replace separators -2			\$0.00	C	11/14/2006 8:00	33 days
<b>1.3.4.4.4</b>	<b>Additional Separators</b>			<b>\$0.00</b>		<b>4/1/2003 8:00</b>	<b>1044 days</b>
1.3.4.4.4.1	develop lattice/helix concept			\$0.00	C	4/1/2003 8:00	66 days
1.3.4.4.4.2	develop magnet/separator concept			\$0.00	C	4/1/2003 8:00	88 days
1.3.4.4.4.3	Decision on separators/magnets (Milestone			\$0.00		7/31/2003 17:00	0 days
<b>1.3.4.4.4.4</b>	<b>Long Separators</b>			<b>\$0.00</b>		<b>8/1/2003 8:00</b>	<b>780 days</b>
1.3.4.4.4.4.1	design long separators			\$0.00	A	8/1/2003 8:00	66 days
1.3.4.4.4.4.2	procurement 14 long separators			\$1,300,000.00	A	11/3/2003 8:00	132 days
1.3.4.4.4.4.3	setup separator production			\$100,000.00	B	2/3/2004 8:00	22 days
1.3.4.4.4.4.4	fabrication+testing first long separator			\$0.00	A	5/5/2004 8:00	88 days
1.3.4.4.4.4.5	fabrication+testing 12 long separators			\$0.00	A	9/6/2004 8:00	440 days
1.3.4.4.4.4.6	installation design			\$0.00	B	11/3/2003 8:00	132 days
1.3.4.4.4.4.7	installation fabrication			\$50,000.00	C	5/5/2004 8:00	44 days
1.3.4.4.4.4.8	long separator installation			\$0.00	B	5/29/2006 8:00	44 days
1.3.4.4.4.5	commission high voltage separators			\$20,000.00	C	12/29/2006 8:00	22 days
1.3.4.4.4.6	new helix commissioning			\$0.00	B	1/29/2007 17:00	44 days
1.3.4.4.4.7	increased BB separation operational (miles			\$0.00		3/30/2007 17:00	0 days

# Longer Separators



# Lumi-Leveling Issues

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- Needed for detectors to reduce number of interactions per crossing:
  - still not certain at what level
  - not an issue now
- will impact the integrated luminosity
- There are operational concerns such as tune and orbit control over a range of  $\beta^*$  values and control of the beam halo rates and beam halo scraping during the leveling process.
- Plan:
  - some experiments possible

# Alignment : Tevatron Magnet Rolls

